Metasomatism in the lithospheric mantle beneath the Calatrava volcanic field: constraints from peridotite xenoliths of the Cerro Gordo volcano

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INTRODUCTION

The Calatrava volcanic field (CVF) comprises about 250 volcanic centers in an area of ~5000 km^2. Detailed studies on mantle xenolith suites have been focused on the Cerro Pelado (Villaseca et al., 2010, and references therein) and the El Aprisco (González-Jiménez et al., 2014) volcanoes, and on other CVF edifices (e.g., Andía et al., 2018; García Serrano et al., 2019). The Cerro Gordo (CG) volcano is a composite edifice made by a scoria cone with short lava flows, which was partially destroyed during an explosive stage generating a maar with pyroclastic surge deposits. Some lenticular cm-sized mantle fragments appear dispersedly within these pyroclastic layers. All the sampled peridotite xenoliths are spinel lherzolites, most of them having amphibole in accessory modal amounts. No previous reference on mantle xenoliths was known from this volcano.

PETROGRAPHY OF THE XENOLITHS

Most of the studied xenoliths are medium- to coarse grained porphyroclastic lherzolite. The most common porphyroclasts are olivine (44-63 modal %) and the two pyroxenes (in similar amounts), commonly rimmed by fine-grained secondary clinopyroxene, olivine, spinel and glass (reaction zones). Primary amphibole is preserved in some xenoliths, but we interpret the clusters of clinopyroxene, olivine and spinel neoblasts within vesicular colourless glass to represent former amphibole. Orthopyroxene is commonly strongly corroded in these reaction zones. Some lherzolites have secondary orthopyroxene either in reaction zones, symplectitic to amphibole or interstitial to Si-poor spongy clinopyroxene and olivine.

WHOLE-ROCK CHEMISTRY

The chemical composition of four samples with suitable size has been obtained. They define a low FeO and TiO_2 suite when compared to other CVF xenoliths. There are two groups of lherzolites: enriched (group-1) and depleted (group-2) in LREE-Th-U, but with similar HREE-Y-Zr-Hf contents.

MINERAL MAJOR ELEMENT CHEMISTRY

Olivine in depleted lherzolites has a higher Mg# [MgO/(MgO+FeO) on a molecular basis] (91.9-92.4) than in group-1 lherzolites (89.7-90.6).
Orthopyroxene also shows the above slight difference, with Mg# values similar to those of olivine: 91.8-92.3 (group-2) and 89.1-90.9 (group-1). Secondary orthopyroxene in group-1 lherzolites have lower Al, Cr, Ti (and slightly higher Mg) contents than primary crystals.
Clinopyroxene has also higher Mg# in group-2 lherzolites. Moreover, they show higher Na, Al and Cr contents than in lherzolites-1. Secondary neoblasts show a divergent chemical evolution depending of the chemistry of the associated intergranular glass: Al-Cr-Ti-rich if the glass is basaltic trachyandesite, and Mg-Ca-rich (and Ti-Al-Cr-poor) when it is andesitic.
Amphibole only appears in group-1 lherzolites (up to 8 modal%) and it is classified as pargasite. It is very similar in major elements to those from groups 3 and 4 from the El Aprisco xenolith suite, with the exception of lherzolite 110858, whose amphibole is remarkably K-(up to 0.6 wt%) and Cr-rich.
Spinel shows a wide range of Mg# (0.70-0.78), Cr# (0.09-0.22) and Al_2O_3 (60.0-47.8 wt%) in both lherzolite groups. Secondary spinel is enriched in Cr and depleted in Al-Mg with respect to the primary one.
Vesicular glass only appears in two group-1 lherzolites. When associated to amphibole breakdown it is basaltic trachyandesite, but where amphibole is absent, the glass is andesitic, showing lower Na-K-Ti-Al and higher Mg-Ca contents.
Both lherzolite groups yield similar pressure ranges (8.5-11.5 kbar), although temperature estimates are lower in group-2 (660-690 ºC) than in the group-1 (805-1050 ºC).

MINERAL TRACE ELEMENT CHEMISTRY

Chondrite-normalized clinopyroxene REE patterns of group-1 lherzolites depicts an almost continuous variation from the N-MORB-like pattern of the depleted lherzolite 117150 (group-2) towards the LREE-enriched pattern shown by lherzolite 110858 (Fig. 1). A similar compositional trend is also evident in primitive mantle-normalized multi-element diagrams, where patterns depart from a base profile represented by the depleted 117150 sample (not shown).

Amphibole has similar REE and multi-element patterns than the associated primary clinopyroxene, suggesting a chemical equilibrium between them. In fact, amph/cpx trace element ratios are close to 1 except for Nb-Ta and Rb-Ba, strongly fractionated to amphibole, as typical of other peridotite suites (Raffone et al., 2009).

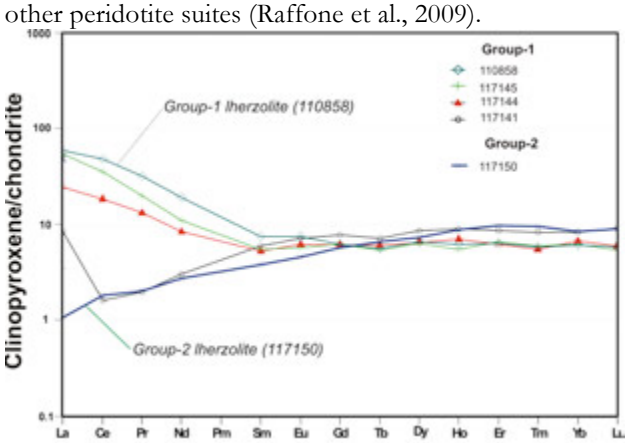

***Fig 1**. Chondrite-normalized REE patterns of primary clinopyroxene.*

DISCUSSION

Partial melting of the mantle sources

Valuable information about the characteristics of the lithospheric mantle beneath the Cerro Gordo volcano before metasomatism can be gained through the mineralogical and geochemical features of the group-2 xenoliths, in which amphibole is absent and enrichment in the most incompatible elements (LREE, LILE, Th, U) is not observed. Partial melting modelling using HREE-Y in clinopyroxene indicates low melting degrees (mostly < 5%).

Origin of the glasses

Glass related to amphibole breakdown (110858 lherzolite) has the same REE and multi-element patterns than the associated corroded amphibole. The thermal impact, combined with the sudden decompression underwent by the xenolith after entrainment in the host volcanic magma, could have triggered the breakdown reaction. The presence of Ti-Al-rich and Mg-poor clinopyroxene-2 is typical of amphibole breakdown reaction in experimental studies (e.g., Shaw, 2009).

Metasomatism of the xenoliths

Clinopyroxene exhibiting a variable degree of enrichment in LREE, LILE and Th-U-Pb contents is likely of metasomatic origin. The high Ti/Eu ratios of this mineral in all lherzolites suggest reaction with silicate melts rather than carbonate-rich ones. The composition of metasomatic melt in equilibrium with clinopyroxene, calculated using partition coefficients of basaltic systems, is characterized by a flat REE pattern (from Sm to Lu), that is unlikely to be related to alkaline melts (e.g., Calatrava magmatism). The marked negative Nb-Ta anomaly of these melts and the high Ti/Nb ratios of the associated amphibole are also indicative of a subduction-related metasomatic agent.

The variable LREE enrichment of single clinopyroxene grains in some samples, along with the absence of MREE and HREE fractionation, suggest that all the REE patterns shown by the CG lherzolites can be explained by a single metasomatic event during a reactive porous flow process. This process leads to changes in trace element concentrations as a function of distance from the melt flow channel (e.g., Ionov et al., 2002). The higher modal amount of amphibole in the more LREE-enriched lherzolites and its significant equilibrium with primary clinopyroxene suggest a vicinity of those samples with the metasomatic conduit produced by the percolation of subduction-related liquids.

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